Understanding Localized Movements and Habitat Associations of Summer Flounder in Chesapeake Bay Using Passive Acoustic Arrays

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Submitted by:

Mary C. Fabrizio
Mark J. Henderson
Jon A. Lucy

Department of Fisheries Science
Virginia Institute of Marine Science
College of William and Mary
Gloucester Point, VA 23062

Executive Summary

Although the spawning migration of summer flounder *Paralichthys dentatus* from estuarine and coastal waters to the shelf break is well described, relatively little is known about the distribution and movements of summer flounder in inshore waters. According to recent results from the Virginia Game Fish Tagging Program, small fish (<16.5 inches or 419 mm total length [TL]) appear to exhibit some degree of site fidelity during the period of estuarine use (Lucy and Bain 2006). We postulated that size may be an important factor contributing to variation in summer flounder movements and distributions within Chesapeake Bay. In this study, we used acoustic tags to study habitat associations and localized movements of small and large summer flounder at three sites in lower Chesapeake Bay: Gloucester Point, York Spit light, and Back River reef. We also investigated the effects of tides, light levels, temperature, and barometric pressure on small-scale movements (on the order of 200-400 m) of individual fish because previous work indicated that environmental factors may affect movements of summer flounder.

Summer flounder exhibited differences in site fidelity which was most pronounced during the summer; fish were retained at Back River reef for longer periods of time than at the other two sites. We also documented movement of fish between our study sites, but this movement was generally unidirectional, with more fish exhibiting movements to Back River reef than to any other site. None of the fish tagged and released at Back River reef were detected at either of the other two sites. Together, these observations indicate that Back River reef may be preferentially used by summer flounder.

Dispersal from Back River reef was gradual throughout the summer and fall, similar to the pattern of dispersal observed on the continental shelf off the coast of New Jersey (Fabrizio et al. 2005). The time of dispersal from the continental shelf was similar to those observed in Chesapeake Bay, with 50% of fish dispersing by 5 September 2003 on the shelf and by 26 August 2006 in the Bay. This implies that there may be similarities in the duration of summer flounder habitat use in Chesapeake Bay and on the continental shelf. We found no statistically significant difference in dispersal of large and small fish from Back River reef. Fish were continuously detected until early December 2006 at Back River reef, but no summer flounder were detected between 5 February 2007 and late March 2007, indicating that tagged fish had dispersed from the York River and Chesapeake Bay (possibly moving to offshore spawning sites). Summer flounder returned to our Chesapeake Bay sites at the end of March 2007.

Time of day, tidal stage, temperature, and barometric pressure affected summer flounder movements over scales of 200-400 m at Back River reef. We detected and documented significant variation in activity levels among individual fish, but overall, fish were more active during night than during the day, and more active at slack tide than during either ebb or flood tides. Fish size was not a significant factor in accounting for variability in mean activity levels. In addition, fish at Back River reef appeared to partition site use on the basis of size.

In summary, activity levels are highly variable among individual fish, and summer flounder movements on the order of 200-400 m are affected by environmental characteristics such as temperature and tides. We also observed large-scale (>1 km) movements of fish, including the movement of fish from Gloucester Point and York Spit light to Back River reef. The appearance of Gloucester Point-tagged fish in the mainstem of Chesapeake Bay during the fall was suggestive of directed movements, such as those associated with migration to offshore spawning sites.

Introduction

Summer flounder *Paralichthys dentatus* use different marine and estuarine habitats during the course of development to the adult stage, when they are prosecuted by recreational and commercial fisheries along the US coast from Massachusetts to North Carolina (Terceiro 2001). Adult summer flounder are targeted by the recreational fishery in the spring and summer when they migrate to coastal and estuarine waters to feed, grow, and prepare for spawning. In Chesapeake Bay, adult and juvenile summer flounder inhabit the estuary from March through November (Montane and Lowery 2005; R. Latour and C. Bonzek, pers. comm.). Adult fish migrate towards the continental shelf break in the fall to spawn off the coast of New Jersey, Virginia, North Carolina, or south of Cape Hatteras (Kraus and Musick 2001). Although the basic life history pattern of habitat use and movement is well known, relatively little is known about the distribution and movements of summer flounder in inshore waters. According to recent results from the Virginia Game Fish Tagging Program, fish less than the 2006 minimum size (16.5 inches or 419 mm total length [TL]) appear to exhibit some degree of site fidelity during the period of estuarine use (Lucy and Bain 2006). Based on these results, and discussions with recreational fishers, we postulated that size may be an important factor contributing to variation in summer flounder movements and distributions within Chesapeake Bay. In this study, we used acoustic tags to study habitat associations and localized movements of small (<16.5") and large (>16.5") summer flounder at three sites in lower Chesapeake Bay.

Previous studies of the movement and distribution patterns of summer flounder have primarily used traditional mark-recapture techniques. Mark-recapture (or tagging) studies are commonly used in fisheries to understand movement of fish as well as population parameters such as survival and emigration. Tagging studies, such as the Virginia Game Fish Tagging Program, depend on the ability to mark sufficient numbers of fish to provide a good indication of population-level processes affecting the numbers, movement, and distribution of individuals. Ecological inferences from tagging studies of summer flounder from Chesapeake Bay have been limited by either low recapture rates or by complexities of the experimental design. For example, Kraus and Musick (2001) used mark-recapture data from 10,607 juvenile summer flounder (<290 mm TL) tagged and released in Chesapeake Bay and Virginia coastal waters to examine the question of stock structure; most of the fish recaptured after 40 days at large moved north and were recaptured in coastal states from Maryland to Connecticut. However, these observations were based on extremely low recapture rates (0.2%) and may not reflect the movement of fish tagged from parts of the bay not studied (e.g., structured sites; Lucy and Bain 2006).

Recapture rates from the VA Game Fish Tagging Program have been considerably higher (~10%) and data collected from this program have provided some indication of how small summer flounder use habitats within Chesapeake Bay (Lucy and Bain 2007). Since 2000, recreational anglers participating in this program released over 36,000 tagged summer flounder within the Virginia portion of Chesapeake Bay. These release sites include inlets (e.g., Rudee Inlet), bridges (e.g., Hampton Roads Bridge Tunnel), and fishing piers (e.g., Buckroe Pier [Hampton,VA], Gloucester Point pier, and Yorktown beach jetties). Over this period a total of 3,578 recaptures was reported for summer flounder tagged as 229 - 381 mm [9-15 inch] fish. Patterns of recapture indicate that fish may use structured habitats in coastal areas for extended periods of time, possibly up to 150 days (Lucy and Bain 2006; Lucy and Bain 2007). This suggests that young flounder may use estuarine habitats in Chesapeake Bay for longer periods of time than fish occupying similar habitats in New Jersey, where young-of-the-year summer flounder (156-312 mm TL) emigrate from salt-marsh creeks within 50 days of release (Rountree and Able 1992). We postulate that small fish (229-381 mm TL) in Chesapeake Bay may exhibit some site fidelity or perhaps have small home ranges during the period of bay residency, remaining closely associated with structures or highly productive areas preferred for feeding and refuge.

In recent years, individual fish movements, home ranges, dispersal rates, and habitat use have been studied with ultrasonic telemetry (e.g., Hooge and Taggart 1998; Arendt et al. 2001; Cote et al. 2003; Parsons et al. 2003; Lowe et al. 2003; Heupel et al. 2004). This technology is similar to radio-tracking technology commonly used in wildlife studies, but uses acoustic signals in the ultrasonic range (e.g., 60-80 kHz) because higher frequency signals are absorbed rapidly in water (Pincock and Voegeli 2002). To date, only three studies of summer flounder have been conducted with this technology. The first was applied to young-of-the-year fish (210-254 mm TL) in a New Jersey marsh creek but used only 9 fish (Szedlmayer and Able 1993). A second study included fish ranging in size from 268 to 535 mm and involved both active and passive tracking of fish in and around Great Bay-Little Egg Harbor, New Jersey (Sackett et al. 2007). This study, based on 53 fish tagged in 2003 and 2004, examined the dynamics of summer flounder emigration from tidal creeks (Sackett et al. 2007). The third study involved 24 summer flounder >265 mm TL passively monitored off the New Jersey coast (Fabrizio et al. 2005). Although the latter work addresses summer flounder use of continental shelf habitats and intra-site movements, results from that work may be compared with results from this study and provide insights on patterns of movement for summer flounder in different coastal habitats.

Movements and habitat use may be studied with ultrasonic telemetry methods, but when passive monitoring is used, the properties of the study site must be taken into consideration prior to designing the spatial layout of the acoustic system. For instance, acoustic “gates” consisting of monitoring receivers positioned perpendicular to the direction of fish movement may be used in areas that are relatively narrow or otherwise confined by land on two or more sides. Gate designs are optimal for studies of fish movements in streams or rivers (e.g., to study the outmigration of Atlantic salmon smolts in Maine rivers, J. Kocik, pers. comm.). In other cases, a study site may be encircled by receivers; this type of design is suitable for studies of some marine protected areas. Other habitats require the use of an acoustic grid or a more complex arrangement of monitoring receivers that permits detection of acoustic signals within study sites of various shapes and within portions of study sites (e.g., among two or more bottom habitat types; Fabrizio et al. 2005). Prior to field implementation, optimal distances between adjacent receivers must be determined using a range test because detection distances of receivers are highly dependent on the environment (Pincock and Voegeli 2002): shallow water, the presence of vegetation, turbidity, wave action, and the presence of soniferous organisms affect the actual results obtained. The range test provides site-specific information on the likelihood of signal detection by a receiver as a function of distance between the transmitter (emitting the signal) and the receiver (detecting and decoding the signal). A benchmark range for saltwater environments is about 400 m (www.vemco.com). Results from a range test are then used to determine suitable placement of monitoring receivers.

The objective of this study was to describe and compare movements of sub-legal and legal-sized summer flounder in lower Chesapeake Bay; we defined legal size as 16.5 inches (419 mm TL), which was the size limit in effect in 2006. The description of the movement of summer flounder includes an examination of the role of tides, barometric pressure, and water temperature on within-site movements, and the fidelity of fish to structured and unstructured sites. We examined the effect of tides and barometric pressure on movement because previous studies reported tidal movements of young-of-the-year summer flounder in salt marsh creeks (Rountree and Able 1992) and movements in response to barometric pressure changes (Sackett et al. 2007).

Field Methods

The field portion of this project was conducted in three phases: (1) deployment of acoustic receivers, (2) release of summer flounder with surgically implanted transmitters, and (3) retrieval and quality assurance of acoustic data.

Deployment of acoustic receivers

We examined summer flounder site fidelity, habitat use, and movement at three study sites in the Virginia waters of Chesapeake Bay: Back River reef, Gloucester Point piers, and York Spit light. Although we originally proposed to establish receiver arrays at Grandview pier, we abandoned this site because during early 2006, the remnants of Grandview pier had been removed (the pier posed a hazard to navigation). Back River reef, a nearby artificial reef, was chosen to replace Grandview pier as one of our structured sites. The York Spit light area was similar in depth to Back River reef, but lacked structure. The two structure sites (Gloucester Point piers, Back River reef) are known to be used by summer flounder (J. Lucy, *pers. obs.*). We postulated that information from York Spit light would be useful in interpreting the significance of structure to site fidelity and movement.

Prior to deployment of receivers, we conducted several range tests to determine the maximum distance at which a transmitter can be detected. This test is necessary because the distance at which the acoustic transmitter can be detected varies depending on site-specific environmental parameters (depth, salinity, vegetation, etc.). Range tests were conducted at each of the three study sites from a small vessel using a single moored VR2 (VEMCO) receiver equipped with an omnidirectional hydrophone in May 2006. To determine the distance at which a transmitter is no longer detected by the receiver, an acoustic transmitter (V9-2L-R256, transmitting at 69 kHz; VEMCO) was placed in the water at progressively greater distances from the receiver. Based on this test, the optimal detection distances were: 400 m at Back River reef, 350 m at Gloucester Point piers, and 200 m at York Spit light (Figure 1). We deployed 12 receivers at Back River reef, 13 receivers at York Spit light, and 1 receiver at Gloucester Point (Figure 2) from the *R/V Pelican* on 13 June 2006. Four other receivers were deployed from fixed piers at Gloucester Point (Figure 2).

Each buoyed receiver was attached to a mushroom anchor and a large buoy was used to mark its location. In addition to the buoy, the GPS position of each receiver was recorded. Some of the receiver-mooring arrays were equipped with temperature data loggers. Receivers passively detected, deciphered, and recorded transmissions from transmitters (within detection range); this information (date, time of day, transmitter identification number) was stored in the memory of the receiver. To obtain these data, the receiver and temperature data logger were retrieved (see below) and interfaced to a personal computer.

Release of summer flounder with surgically implanted transmitters

Summer flounder captured by hook and line and trawling were implanted with acoustic transmitters between 15 June 2006 and 10 July 2006 (Table 1). We implanted 40 fish at each of three sites for a total of 120 fish; our goal was to implant 20 sub-legal and 20 legal-sized fish per site. In 2006, summer flounder greater than 419 mm (16.5 inches) TL were harvestable by recreational fishers in Virginia waters (in 2007, this minimum size was increased to 470 mm

[18.5 inches]). All fish were captured at the study sites and released at the location of capture. Most fish at Back River reef were captured by hook and line, but trawl-captured fish were a significant portion of the fish captured at York Spit light and Gloucester Point (Table 1). Fish ranged from 258 mm (10.2 inches) to 612 mm (24.1 inches) TL.

Each fish was surgically implanted with an individually coded transmitter using procedures established for summer flounder (Fabrizio and Pessutti 2007). Briefly, fish were anesthetized with AQUI-S (a clove oil derivative approved for use as an anesthetic in Australia and New Zealand), a small incision was made on the non-pigmented side of the fish, a beeswax-coated transmitter (9mm x 30 mm; V9-2L-R256, VEMCO) was inserted into the peritoneal cavity, and the incision was stitched using non-absorbable sutures in an interrupted pattern. While the fish remained under anesthesia, size and weight measurements were collected, and an individually numbered T-bar anchor tag (Hallprint tags) was inserted into the dorsal musculature near the tail (this is the same placement used by the Virginia Game Fish Tagging Program). Anchor tags were labeled with a unique identifying number and a phone number to report the recapture. Fish were then resuscitated using ram ventilation and released at the study site.

With the exception of one fish, summer flounder smaller than 265 mm TL were not implanted with transmitters because mortality is high with fish of this size (Fabrizio and Pessutti 2007). Two surgeons performed the implantations in the field, but only after each had been trained and allowed to practice making and closing incisions on dead fish prior to working with live study animals. Several individuals were trained to assist the surgeon (preparation of anesthetic bath, monitoring level of anesthesia, preparation of surgical tools and arena, circulation of anesthetic solution over gills, ram ventilation techniques, and data recording).

All transmitters emitted individual codes which could be used to identify individual fish; transmitters were configured to ensure battery power for the duration of the study. Following Fabrizio et al. (2005), we used coded transmitters 30 mm long and 9 mm in diameter with a delay time varying between 60 and 180 seconds. With this configuration, battery life was about one year.

To alert anglers to the importance of releasing these tagged fish and reporting recaptures, we initiated a widespread advertising campaign that included a poster (Appendix I), press releases, and an appearance on a local radio fishing show. We obtained five reports of recaptured fish from anglers, four of which were re-released alive (Table 2). Of the reported recaptures, four fish were captured at Back River reef, and one was captured at the Gloucester Point fishing pier; we received no reports of fish recaptured at York Spit light.

Retrieval and quality assurance of acoustic data

Acoustic receivers were first retrieved and downloaded in August 2006; the four fixed arrays at Gloucester Point were downloaded on 9 August 2006; the remaining receivers were downloaded on 22-23 August 2006 from the *R/V Pelican*. Once each receiver was downloaded, the array was reconstructed and redeployed. With the exception of a single receiver from York Spit light, all receivers contained acoustic data. The York Spit receiver malfunctioned and was replaced during redeployment. A total of 554,486 detections was recorded for the period 15 June to 23 August 2006. The majority of the detections were from receivers at Back River reef (293,342), followed by Gloucester Point (136,422) and York Spit Light (124,722).

These acoustic data contained a small number of detections that could not be attributed to our study fish (N=176, 0.03%). These entries were removed from the database. We also removed multiple detections of the same ping at adjacent receivers. Changes in environmental conditions (e.g., salinity, sea state, and biological organisms in the water column) can influence the detection range of the receivers such that two or more adjacent receivers may detect and record the same signal. To simplify the data, only the first recorded ping was retained in the data set and subsequent detections of the same ping (defined as any detection of the same transmitter within 60 seconds) were removed from the database. Sixty seconds was chosen because this is the minimum duration between pings for an individual transmitter. A total of 58,990 (10.6%) multiple pings was removed from the data set leaving a total of 495,320 detections.

We also deleted a small number of data records that were known to be erroneous (N=83, 0.01%). For example, due to interference from acoustic noise, receivers recorded pings from transmitters before they were implanted in a fish and released. Other erroneous detections were from transmitters known to be at one of the other three sites and from transmitters that were removed from the study (due to angler capture). Removal of these pings from the database resulted in 495,237 valid detections for subsequent analyses.

Retrieval and final download of the acoustic receivers at Back River reef, Gloucester Point piers, and York Spit light occurred on 27 March 2007 from the *R/V Pelican*. Three receivers from the Gloucester Point pier site malfunctioned, but fortunately, receiver data downloaded from this site in October 2006 indicated that few fish remained in the area by that time. The two functioning receivers at Gloucester Point piers detected only 4 fish from October 2006 to March 2007, and these were intermittent detections. In March 2007, we were unable to locate five receivers at Back River reef, one receiver at York Spit light, and one receiver at the Gloucester Point piers. We conducted a side-scan sonar survey from the *R/V Elis Olsen* on 14 May 2007 to locate the missing receivers at Back River reef and York Spit light. Based on side-scan images, we located three of the missing receivers at Back River Reef; in June 2007, scuba divers successfully recovered the three receivers. We postulate that the 'missing' receivers were entangled by ships and dragged away from the Back River reef and York Spit light; we found evidence to indicate that the receiver at the Gloucester Point fishing pier was cut loose from its attachment to the pier.

Receivers recovered in March and June 2007 contained a total of 211,604 detections spanning the period 22 August 2006 (previous download date) to 23 March 2007. Careful examination of the data revealed three mortalities, one at each site (Table 4). Two of the mortalities (tag # 130 and tag # 49) occurred shortly after release. The third mortality (tag# 78) occurred three weeks after release and is presumed to be a catch-and-release mortality because this fish was last detected alive near the Gloucester Point fishing pier. After eliminating detections from fish that had died (N=46,555, 22.0%), unknown acoustic tag numbers (N=5,940, 2.81%), multiple detections of the same ping (N=13,404, 6.33%), and invalid detections (N=18, 0.01%) we retained 145,687 valid detections for the period 22 August 2006 to 23 March 2007. We also removed detections from the first download attributable to the fish that were discovered dead (N=38,897, 7.01%), which resulted in 456,340 valid detections from the first download. Combining data from all downloading events, we obtained 602,027 detections of acoustically implanted summer flounder in this study.

Statistical Methods

Summer flounder acoustic data were analyzed for size-specific differences in movement and habitat use. Differences in site fidelity were also examined using simple descriptive statistics to characterize the length of time summer flounder were found at a given site. Inter-site movement of summer flounder, which we described using simple statistics, occurred when fish moved away from the release site and entered into the acoustic range of another study site. Size-specific dispersal rates were estimated for summer flounder at Back River reef; we did not estimate dispersal rates from the other two sites due to the low number of fish that were present shortly after release. Where possible, results from this study were compared with those suggested by the Virginia Game Fish Tagging Program.

Dispersal rates, which describe movement of fish away from a site, were estimated using the Kaplan-Meier (KM) approach (Bennetts et al. 2001). Here, we defined dispersal following Bennetts et al. (2001); dispersal is indicated by movement from one predefined area to another; fish are considered to have dispersed when they are no longer detected at the study site, in this case, Back River reef. The KM method is a nonparametric approach, requiring no assumptions about the underlying hazard function. KM estimators are robust, have well described variances (Pollock et al. 1989a), and can be modified to permit staggered entry of individuals (Pollock et al. 1989b). We used the staggered entry design because for a given site, not all fish were implanted and released on the same day. Four fish implanted and released at York Spit light later resided at Back River reef. The total sample size for the dispersal analysis was 43 fish: this included the 4 fish that moved to Back River reef from York Spit light, as well as the 39 fish tagged and released alive at Back River reef.

The KM model also accommodates censored data; we identified censored observations as fish whose fate could not be determined conclusively. For instance, if a fish was last detected within the center of the acoustic array at Back River reef, we did not know if the fish was harvested by an angler (and therefore, dead) or if it indeed dispersed because we have no evidence that the fish crossed one of the perimeter receivers. Thus, such observations are censored. Censoring is a commonly applied statistical practice to address uncertainty in the assignment of fates; for these type of data, statistical methods that ignore censoring are biased (Collett 2003). Dispersal functions were estimated for all fish and for large (>430 mm TL) and small (<430 mm TL) fish separately. Here, we used a slightly different size to define small and large because this categorization provided for a more even sample size distribution among size categories. The log-rank test was used to test the hypothesis of no difference in dispersal functions of large and small fish. The statistic used for the log-rank test is *W*, which has a chi-square distribution with 1 degree of freedom (Collett 2003). Dispersal rates of summer flounder from this study were compared to those reported by Fabrizio et al. (2005).

In addition to large-scale movements (dispersal away from the sites), we examined smaller-scale movements of summer flounder at Back River reef using an activity index. (Again, we did not use acoustic data from fish released at York Spit light and Gloucester Point piers because few fish were present at these sites for long enough periods of time.) The activity index is an indicator of between-station movement – that is, movement on the scale of 100s of meters (Fabrizio et al. *in prep*.). We calculated the activity index as the number of times a fish is detected at an adjacent station within a given time period; here, we used a 3-hour period based on nautical twilight at dawn and dusk. In this manner, activity indices for each fish were obtained during four nautical time periods each day: dawn, day, dusk, and night; day and night periods were identified as the 3-hour periods equally distant from dawn and dusk. The times of nautical twilight for each day of our study were acquired from the Astronomical Applications Department of the US Naval Observatory (http://aa.usno.navy.mil/data/docs/RS_OneYear.php). We also defined four time periods each day corresponding to tidal stage: flood, slack after flood, ebb, and slack after ebb, and calculated activity indices for these three-hour tidal periods.

Activity indices of summer flounder were examined relative to time (time of day, date, and week), fish size, tidal stage, barometric pressure, and temperature using a repeated measures analysis of variance (ANOVA) approach. Because acoustic receivers recorded data throughout the day, activity indices for a given fish are serially correlated and are thus, repeated measures. Using this approach, we tested for equality of the mean summer flounder activity level (movement) for various time periods (nautical time periods, days, and weeks) and across environmental changes (temperature, barometric pressure). We used the MIXED procedure in SAS to fit a linear mixed model with repeated measures that incorporated random variation among individual fish. The statistical model we fit to the data was:

$$Y = X\beta + Zu + \varepsilon$$

where **Y** is a vector of observations of individual fish response (activity indices), **X** is a matrix describing the fixed effects structure, β is a vector of fixed parameter effects, **Z** is a matrix describing the random effects structure, ***u*** is a vector of random model effects (individual fish), and ε is a vector of residuals (Verbeke and Molenberghs 2000). The variance-covariance matrix describing the residuals is designated by the matrix **R**. Because we considered a single random factor, ***u*** (individual fish), we assumed the random effects were distributed as a normal distribution with mean 0 and variance-covariance matrix **G**; this is a reasonable assumption because the number of fish included in the model was fairly large (N=50). As with all linear mixed models, we made the assumption that the distribution of the response variable (activity index) is normal. We transformed the activity index using natural logarithms as this provided more homogeneous variances of the response variable among different size fish. The modeling results we present here are a preliminary investigation of these complex intensive repeated measures data.

In this model, we included the following fixed effects: size (small vs. large), temperature, barometric pressure, tidal stage or nautical time period, date, week and the two-way interaction between nautical time period × date or tidal stage × date. Additional two-way interactions that could conceivably be included in the model were those involving size: size × date, size × nautical time period, size × tidal stage, size × temperature, and size × barometric pressure, but inspection of the interaction plots revealed the absence of strong interactions with size. Mean activity of large and small fish did not appear to change in significantly different ways with changes in nautical time period, tidal stage, week, barometric pressure, or temperature. Based on this, we excluded size interactions from the model.

Because of the nonalignment of tidal stages and nautical time periods, we could not fit a model with both nautical time period and tidal stage effects; note that activity indices were calculated for three-hour periods relative to either nautical twilight *or* tidal stage. Thus, we fit two separate linear mixed models, each based on different time periods (nautical twilight or tidal stage). Individual fish were treated as a random effect in the models because preliminary observations indicated that activity levels varied greatly among individual fish. We also attempted to test and fit several variance-covariance structures to describe the correlation between repeated measures (i.e., the nature of the dependencies in **R**), and attempted to use AIC to assess fit of these covariance structures; in the MIXED procedure, correlations among errors are modeled by specifying the structure of **R** (Littell et al. 2006; Verbeke and Molenberghs 2000). We postulated that summer flounder activity patterns varied in response to environmental light levels or tidal stage and used linear contrasts to test for differences in mean activity levels of summer flounder during day versus night, during day/dusk versus night/dawn, during slack tide versus flood/ebb, and during flood versus ebb tide (Littell et al. 2006). The model of activity based on nautical time periods included 26 small and 24 large fish, and the model of activity based on tidal stage included 26 small and 25 large fish.

Results

Site fidelity

Summer flounder exhibited differences in fidelities to the three sites over the course of our study period (June 2006 to March 2007), and this was especially pronounced during the summer (Figure 3). Although we implanted and released the same number of fish at each site, we observed differences in the number of individual summer flounder at the three sites from June through March 2007, and especially in the summer (Figure 3). Mean residency times of fish tagged and released at Gloucester Point (11.34 days) and York Spit light (10.79 days) suggest that summer flounder moved quickly out of the detection range of our receivers at theses sites soon after tagging (Figure 3). Mean residency time for fish released at Back River reef was greater (34.82 days) than that observed at the other two sites, and a number of fish remained associated with the reef throughout the summer (Figures 3 and 4). By 23 August 2006, 18 of the 39 fish (46%) released alive at Back River reef remained at the site, compared with only 4 at York Spit light (10%) and 1 at Gloucester Point piers (~3%). These results suggest there may be differences in residency times of fish from the different sites, but direct comparisons cannot be made because the receiver detection areas at the three sites were markedly different.

Fish tagged at York Spit light appear to exhibit a greater tendency to move than fish tagged at Back River reef. This is supported by the observation that 5 out of 9 fish released at

York Spit light and subsequently detected at Back River reef remained at the reef for a longer period of time than the length of time the same fish were detected at York Spit light (Figure 4). We noted another type of behavior among fish released at Gloucester Point and York Spit light: some of these fish were not continuously within range of the receivers but were detected intermittently for several weeks after release (Figure 4). It is unclear if these fish were continuously near the array, but just outside the detection range of the receivers, or if the fish moved significant distances away from the site and periodically returned to the area.

Dispersal from study sites

Dispersal of fish from the three sites occurred at different times. At Gloucester Point, tagged fish were continuously detected through 14 September 2006. From late October to early December, only 4 fish were detected at Gloucester Point, and only for brief time periods (1-5 days). Fish were continuously detected at York Spit light until 27 October 2006. In contrast, summer flounder were continuously detected until early December 2006 at Back River reef. Additionally, two fish were detected at Back River reef from the end of December until early February 2007 (Figure 4). No summer flounder were detected after 5 February 2007 through late March 2007, indicating that tagged fish had dispersed from the York River and Chesapeake Bay (possibly moving to offshore spawning sites). Summer flounder returned to our Chesapeake Bay sites at the end of March: four fish were detected at Back River reef, one of which (tag #95) was later detected at York Spit light. Interestingly, three out of four of these fish had been released at Gloucester Point (Table 5), suggesting that fish that frequented more upriver sites returned to the Bay before those that typically frequented lower river and bay sites.

We used the Kaplan-Meier approach to estimate dispersal rates of summer flounder from Back River reef. Fish quickly dispersed from Gloucester Point and York Spit light, resulting in few fish with which to estimate dispersal rates, so we refrained from such estimation for those sites. Summer flounder dispersal from Back River reef was gradual throughout the summer and fall (Figure 5). About 50% of the fish dispersed from the reef by the 10th week (20-26 August 2006) and 75% dispersed by the 16th week (1-7 October 2007). By the 19th week (22-29 October 2006), less than 10% of the fish remained at Back River reef. The log-rank test of differences among the dispersal functions for small (<430 mm TL) and large (>430 mm TL) fish was not significant, indicating that size had no effect on dispersal of summer flounder (W=0.488, P=0.516) (Figure 6). The confidence intervals around the dispersal functions for large and small fish were large because of the low number of fish at Back River reef (19 small and 24 large fish). Larger sample sizes (i.e., additional fish implanted with transmitters) may have permitted us to detect differences in dispersal among small and large fish during August, September, and October (weeks 7-19), when it appeared that small fish moved away from Back River reef at a faster rate than large fish.

Inter-site movements

A total of 28 summer flounder was detected at a site different from the release site (Table 3). This inter-site movement was generally unidirectional and more fish exhibited movements to Back River reef than to any other site. Fish detected during March 2007 were not considered in this analysis because we believe these detections were from fish that had re-entered the study sites after having migrated out of the bay for spawning or migrated to deeper water sites. A total of 16 of the 40 fish (40%) tagged and released alive at Gloucester Point piers was later detected either at Back River reef (8 fish) or York Spit light (8 fish) during 2006. These fish ranged in length from 274 to 509 mm TL (10.8" – 20.0"). Ten of the 16 fish (63%) were detected in the main stem of the bay during late November through December. The remaining six fish were detected at their destination site in July (2 fish), September (2 fish), and October (2 fish). On average, long periods of time elapsed between the time a fish was last detected at Gloucester Point piers and when a fish was subsequently detected at Back River reef (2,482.9 hrs or 103.5 days) and York Spit light (1,792.9 hrs or 74.7 days). This implies that most of these fish were not moving directly between the sites. Additionally, 12 of the 39 (31%) summer flounder tagged and released alive at York Spit light were later detected at Back River reef. Two of these individuals later returned to York Spit light. Two of the 8 fish that moved from Gloucester Point to York Spit were also later detected at Back River reef. The 14 fish that moved from York Spit light to Back River reef ranged in length from 258 to 572 mm (10.2" – 22.5"), and 9 of the 14 fish (64%) completed this movement in June and July. The remaining fish moved from York Spit light to Back River reef in late October to early November (3 fish) or in early December (2 fish). The average time to move between these sites was less than the time to move between Gloucester Point piers and the main stem, implying that at least some of these fish were moving in a more directed manner between York Spit light and Back River reef. None of the fish tagged and released at Back River reef were detected at either of the other two sites. This observation indicates that Back River reef may be preferentially used by summer flounder and that once summer flounder inhabit this site, they are not likely to disperse.

Activity patterns of summer flounder based on nautical time periods

Inferences from linear mixed models can vary greatly depending on the structure of the model, that is, models with or without individual fish as a random component provide different results of the tests of fixed effects such as size and temperature. Therefore, we tested the significance of the added variation attributable to individual fish using a test based on the *z*-score (Littell et al. 2006). This test indicated that the covariance parameter associated with individual fish was significantly different from zero (z=3.81, P<0.01) in the model of activity based on nautical time periods. We also fit two types of variance-covariance structures to the data (to model the structure of **R**); the model using an autoregressive function of the errors was better than the model assuming independent errors and compound symmetry of the variance-covariance matrix (AIC_{AR} = 12,026.0, AIC_{CS} = 12,394.8). As expected with repeated measures data, the random errors were significantly correlated. The linear mixed model fit to activity data based on nautical time periods for 50 summer flounder at Back River reef included individual fish as a random factor and an autoregressive structure to model the correlated errors (Littell et al. 2006).

Mean activity of summer flounder varied significantly by date (F=9.32, P<0.01), week (F=6.10, P=0.01), and barometric pressure (F=4.19, P=0.04). Mean activity of small and large summer flounder was not significantly different (F=2.36, P=0.13), and temperature (F=3.17, P=0.08) did not affect activity. The interaction of nautical time period and date was insignificant (F=1.09, P=0.35) indicating that activity patterns of summer flounder within a day did not vary through time. About 18% of the variation in activity was attributed to variation among individual fish; the correlation between adjacent nautical time periods was estimated to be 0.244. Although activity levels across nautical time periods were not significantly different at an alpha level of 0.05 (F=2.51, P=0.06), the pre-planned contrast of the mean activity index for summer flounder during the day (least squares mean=0.2269, SE=0.04542) was significantly less than the mean index at night (least squares mean=0.2890, SE=0.04512) ($F=4.67$, $P=0.03$). In addition, mean activity during the night-dawn periods combined was significantly greater than mean activity during the day-dusk periods (pre-planned contrast: $F=4.05$, $P=0.04$).

Activity patterns of summer flounder based on tidal stage

We found significant variation in activity levels among individual fish in the linear mixed model of activity based on tidal stage ($z=3.52$, $P<0.01$). As before, the variance-covariance matrix **R** was better described by an autoregressive function of the errors than by compound symmetry (AIC_{AR} = 15,305.3, AIC_{CS} = 15,777.7). Therefore, the linear mixed model fit to activity data based on tidal stage from 50 summer flounder at Back River reef included individual fish as a random factor and modeled the correlations among the repeated observations using an autoregressive function with lag 1 (Littell et al. 2006).

Mean activity of summer flounder varied significantly by tidal stage ($F=26.50$, $P<0.01$), date ($F=9.73$, $P<0.01$), week ($F=6.43$, $P=0.01$), barometric pressure ($F=9.11$, $P<0.01$), and temperature ($F=5.73$, $P=0.02$). Mean activity levels of small and large summer flounder were not significantly different ($F=2.06$, $P=0.16$). The interaction of tidal stage and date was insignificant ($F=1.80$, $P=0.15$), indicating that activity patterns of summer flounder during a tidal cycle did not vary through time. About 15% of the variation in activity was attributed to variation among individual fish; the correlation between adjacent tidal stages was estimated to be 0.210. Mean activity levels of summer flounder during slack tide were significantly greater than mean activity levels observed during flood and ebb stages (pre-planned contrast: $F=6.95$, $P=0.01$). In addition, mean activity levels during flood tide were not significantly different from mean activity levels during ebb tide (pre-planned contrast: $F=0.54$, $P=0.46$).

Within site distributions

Summer flounder do not use all areas within each study site equally as evidenced by the number of detections per individual at each receiver (Figure 7). This is most apparent at Back River reef where fish spent the most time near receivers BR05 and BR08 (Figure 7a). These two receivers were placed at the western and southern regions of the reef. Other receivers with a large number of detections per individual were BR06, BR07, and BR11. We also observed variations in the mean length of fish at the individual receivers (Figure 8). Mean lengths of fish detected by an individual receiver ranged from 347.23 mm (13.7”) to 487.05 mm (19.2”). The largest individuals, as determined by mean length weighted by the number of detections recorded by each receiver, were found at BR05 (487.05 mm, 19.18”), BR07 (465.03 mm, 18.31”), and BR11 (461.13 mm, 18.15”) (Figure 8). In contrast, individuals at BR08 (397.22 mm, 15.64”) and BR06 (406.21 mm, 15.99”) were, on average, smaller. Interestingly, the largest fish were observed at BR05, the receiver with the most detections per individual, whereas the smallest fish were found at BR03, the receiver with the fewest detections per individual. At Gloucester Point piers (Figure 7b), fish spent the most time near the VIMS ferry pier (GP03) and the fishing pier (GP02). At York Spit light, most of the detections occurred at the periphery of the receiver array and at YS08 (Figure 7c).

Discussion

Results from this acoustic tagging study provide a more complete picture of summer flounder movement and dispersal during the summer residency period in Chesapeake Bay than results obtained to date from conventional tagging studies. Prior to our study, inferences on summer flounder movement patterns were primarily based on recaptures of smaller fish (<419 mm or 16.5”) tagged by the VA Game Fish Tagging Program. Recapture data from the VA Game Fish Tagging Program indicate that small summer flounder exhibited some degree of site fidelity to structured sites (Lucy and Bain 2006). However, recapture data from conventional tagging studies in open systems cannot provide information on the localized movements of fish between the tagging site and the recapture site. Acoustic telemetry data from this study not only provided more detailed information on localized movements of fish, but also yielded information on large-scale movements in the lower bay.

One of the more striking results we observed was the relatively short residency period of fish tagged and released at Gloucester Point. The mean residency time for fish at this site was 10.79 days. This was a shorter residency time than expected based on results from the VA Game Fish Tagging Program, which documented recaptures at Gloucester Point piers 100 days after release (Lucy and Bain 2006). Although these results appear to be somewhat contradictory to those observed in this acoustic study, it is important to note that the highest proportion of summer flounder recaptures from the Game Fish Tagging Program from Gloucester Point piers was reported within 10 days of release, similar to the mean residency time observed for fish tracked with acoustic telemetry. Additionally, a number of fish implanted with acoustic tags were detected at Gloucester Point after they had gone undetected at the site for several weeks. This apparent movement of fish away from, and subsequent return to, the site could result in the pattern of recaptures observed by the VA Game Fish Tagging Program.

Residency times at York Spit light and Back River reef were consistent with what we had previously hypothesized, namely, that structured sites (Back River reef) would retain fish for longer periods than unstructured sites (York Spit light). The mean residency time at York Spit light, the single unstructured site, was 10.79 days. This residency time was less than that estimated for fish from Back River reef (34.82 days), which suggests individuals were preferentially retained at Back River reef (Figures 4 and 5). Individuals tagged and released at Back River reef were more likely to remain at that site than fish tagged and released at York Spit light. Furthermore, four fish that moved away from York Spit light shortly after being tagged subsequently resided at Back River reef for periods ranging from two to four weeks. Although these results are suggestive of a difference in retention at structured and unstructured sites, we are currently unable to make any direct comparisons between these two sites because the areas monitored by the acoustic receivers were quite different.

The relatively long residency time of fish detected at Back River reef allowed us to examine the influence of fish size and a number of environmental variables on individual fish activity patterns using linear mixed models. Results from these models indicate that time of day, tidal stage, temperature, and barometric pressure influence summer flounder movements on the scale of 200-400 m. Fish were more active during times of low light levels (night) than during the day. Fish were also more active at slack tide than during either ebb or flood tides. Fish size was not a significant factor in accounting for variability in mean activity levels. However, mean activity levels of smaller fish were consistently greater than those for larger fish, as evidenced by inspection of simple plots of activity level against various environmental variables. Our sample size was likely too small to observe a statistically significant difference in activities of small and large fish. In addition, we detected and documented significant variation in activity levels among individual fish. We emphasize that the activity index reflects movements over 200-400 m, and therefore, results derived from analyses of activity levels are not necessarily applicable to fine-scale movements, such as those potentially associated with increased vulnerability to capture by the hook-and-line fishery. The activity index we calculated may not be related to fine-scale (<100 m) movements of summer flounder within the reef.

Fish residing at Back River reef preferentially used some areas of the site and appeared to partition site use on the basis of size. As expected, receivers with the most detections per individual were primarily located near the artificial reef structure, thus supporting the notion that summer flounder preferentially associate with structured habitats. A noteworthy result was the observation that fish of different length were not using the same habitats within the reef. From the data we collected, it is unclear what processes may be driving the segregation of small and large fish at Back River reef, but this question could be investigated further.

In an attempt to understand factors associated with dispersal from Back River reef, we estimated the probability of fish dispersal for each week of the study (Figures 5 and 6). A small proportion of fish dispersed from the site soon after they were tagged and released. The remaining fish dispersed at a steady rate throughout the summer and up until the end of October. There was no significant difference between the dispersal probabilities of small and large fish. These results are similar to those observed using a passive acoustic array deployed on the continental shelf off the coast of New Jersey (Fabrizio et al. 2005). As in Chesapeake Bay, summer flounder began dispersing from shelf habitats immediately after implantation in June 2003, and continued to disperse from the site throughout the study period. The dates of dispersal from the continental shelf were also similar to those observed in Chesapeake Bay, with 50% of fish dispersing by 5 September 2003 on the shelf and by 26 August 2006 in the bay. This implies that there may be similarities in the duration of summer flounder habitat use in Chesapeake Bay and on the continental shelf.

Summer flounder that dispersed from the three sites in the fall and winter may have remained in Chesapeake Bay or may have moved offshore to spawn. Trawl survey data from the Bay indicate that some fish (adults and juveniles) remain resident in the Bay throughout the year (Montane and Lowery 2005). We also observed a number of fish that moved to one of the other study sites (Table 3). One common movement corridor was from York Spit light to Back River reef during June and July. Four of the fish that moved along this corridor took up residence at Back River, remaining at the site anywhere from a few weeks to more than one month. Another common movement corridor was from Gloucester Point to York Spit light or Back River reef during November and December. With the exception of a single individual, these fish generally did not remain at the new site for more than 1 to 5 days. Most of these fish passed through the York Spit light and Back River reef areas quickly, and within a few weeks of each other; this observation suggests this movement was part of a directed migration. Unfortunately, without further data we are unable to determine if these fish were migrating out of the Bay or simply moving to deeper waters within the Bay.

Although this study provided insight on the movement patterns of summer flounder within Chesapeake Bay, a number of questions remain unanswered. Evidence suggests that summer flounder do not exhibit long-term (weeks to months) site fidelity at Gloucester Point piers, but we do not know what habitats these fish used after dispersing from the site. One pattern we observed was movement of fish to other (unknown) sites in the York River, followed by a return to the Gloucester Point site some time later. A similar question concerns the fate of fish that dispersed from York Spit light soon after tagging. One possible hypothesis is that summer flounder exhibit two distinct movement patterns: resident and transient. Residents, such as the majority of fish released at Back River reef, remain in the same area for long periods of time (e.g., throughout the summer and fall). Transients, which may include some of the fish released at Gloucester Point and York Spit light, may travel greater distances in search of optimal habitats for foraging or refuge. Another important issue regarding summer flounder movement patterns concerns the proportion of individuals that remain in the bay throughout the year. The decision to leave the bay may be made by an individual fish or by entire cohorts, but our data are insufficient to address this question. Improvements in acoustic tracking technology may help future work focus on these and other habitat-related questions.

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Table 1. Capture and release information for 120 summer flounder implanted with acoustic transmitters, June-July 2006 in Chesapeake Bay.

Study site	First release date	Last release date	Number trawl caught	Number angler caught	Min. size, mm (inches)	Max. size, mm (inches)
Back River reef	06/20/06	07/10/06	4	36	272 (10.7")	606 (23.9")
Gloucester Point piers	06/15/06	06/26/06	20	20	273 (10.8")	509 (20.0")
York Spit light	06/22/06	06/29/06	24	16	258 (10.2")	612 (24.1")
Total			48	72		

Table 2. Summer flounder recaptured by anglers in 2006. The asterisk indicates a fish for which the yellow anchor tag was missing; when cleaning the fish, the angler discovered the acoustic tag, contacted VIMS to report the recapture, and returned the acoustic tag.

Release site	Recapture site	Recapture date	T-bar tag number	Reported fish length	Released alive (Y/N)
Back River	Back River	07/01/2006	FA-152	Unknown	Y
Back River	Back River	07/14/2006	Unknown	19.5”	N*
Back River	Back River	07/15/2006	FA-154	~13”	Y
Back River	Back River	07/30/2006	FA-002	18”	Y
Unknown	Gloucester Pt	Unknown	Unknown	Unknown	Y

Table 3. Movement of 28 summer flounder between three sites in Chesapeake Bay: Back River reef (BR), York Spit light (YS), and Gloucester Point piers (GP). TL is the total length of the fish at the time of tagging, date is the date the fish was detected at the destination site, and time is the number of hours elapsed between detections at the originating site and the destination site. A few of the 28 fish contributed to movement along 2 corridors.

Movement corridor	Number of fish	TL range in mm (inches)	Mean TL in mm (inches)	Date range (2006)	Mean date (2006)	Range of travel time (hrs)	Mean travel time (hrs)
GP – BR	8	291-509 (11.5”-20.0”)	375.5 (14.8”)	24 Jul-24 Dec	11 Nov	649 - 3600	2482.9
GP – YS	8	274-407 (10.8”-16.0”)	335.5 (13.2”)	11 Jul-10 Dec	26 Oct	18 - 3745	1792.9
YS – BR	14	258-572 (10.2”-22.5”)	373.1 (14.7”)	24 Jun-07 Dec	28 Aug	12 - 3209	607.4
BR – YS	2	347-476 (13.7”-18.7”)	411.5 (16.2”)	25 Jun-31 Aug	29 Jul	26 - 57	40.8

Table 4. Description of the three tagged summer flounder that died during this study.

Tag number	Release location	Release date	Mortality date	Length at time of tagging (mm/in)
49	Back River reef	20 June 2006	20 June 2006	522 / 20.6”
78	Gloucester Point piers	19 June 2006	9 July 2006	292 / 11.5”
130	York Spit light	28 June 2006	28 June 2006	612 / 24.1”

Table 5. Description of the three summer flounder released at Gloucester Point in 2006 and detected at Back River reef in March 2007.

Tag number	Release location	Last detection location (before spring)	Last date detected (before spring)	Most recent detection date	Length at time of tagging (mm / in)
73	Gloucester Point	Back River	21 Oct 2007	22 Mar 2007	509 / 20.0”
85	Gloucester Point	Back River	26 Nov 2006	20 Mar 2007	291 / 11.5”
95	Gloucester Point	York Spit	22 Jun 2006	21 Mar 2007	339 / 13.4”

Figure 1. Results from range tests at York Spit light, Back River reef, and Gloucester Point piers. The average interval is the average time between "pings" detected by the receiver. The expected interval, that is, the transmitter ping rate, was eight seconds (horizontal solid line). Receivers at each site were spaced to ensure that at least 50% of the pings would be detected, i.e., the distance at which the average interval between successively detected pings was 16 secs or less (horizontal dotted line). The Gloucester Point range was reduced from 400 m to 350 m because of the low detection range in shallow water (open triangles).

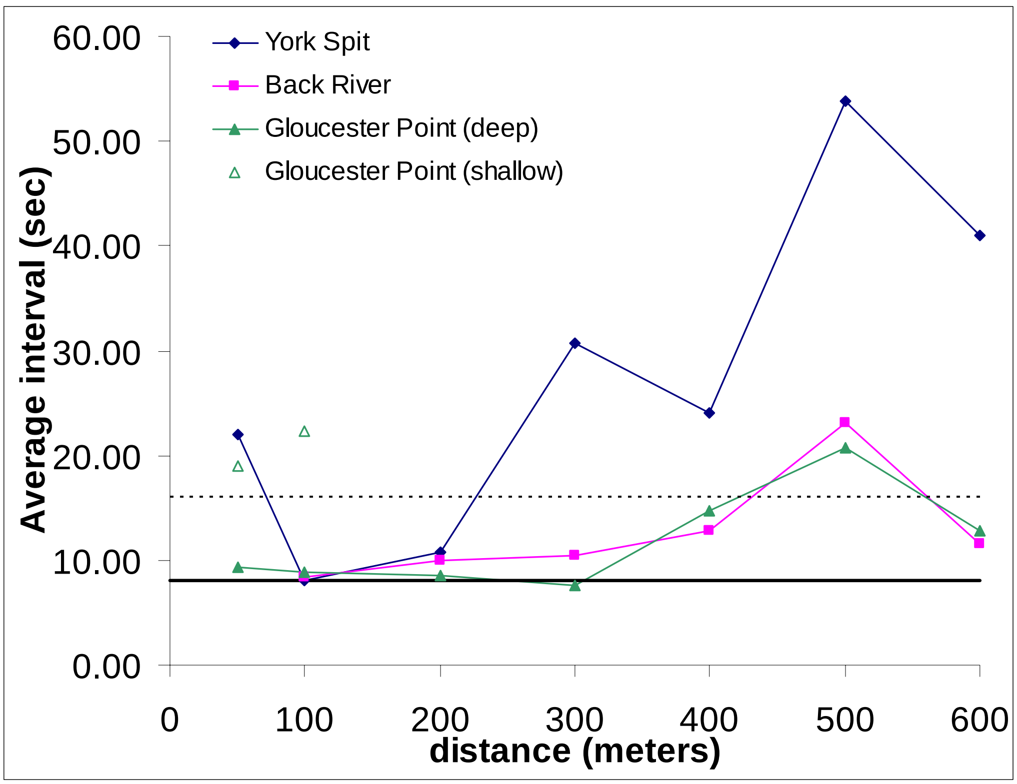


Figure 2. Receiver configuration at a) York Spit light, b) Back River reef, and c) Gloucester Point. Yellow circles represent lighted buoys, red circles represent buoys with no lights, and green circles represent receivers attached to fixed sites (piers and boat launches).

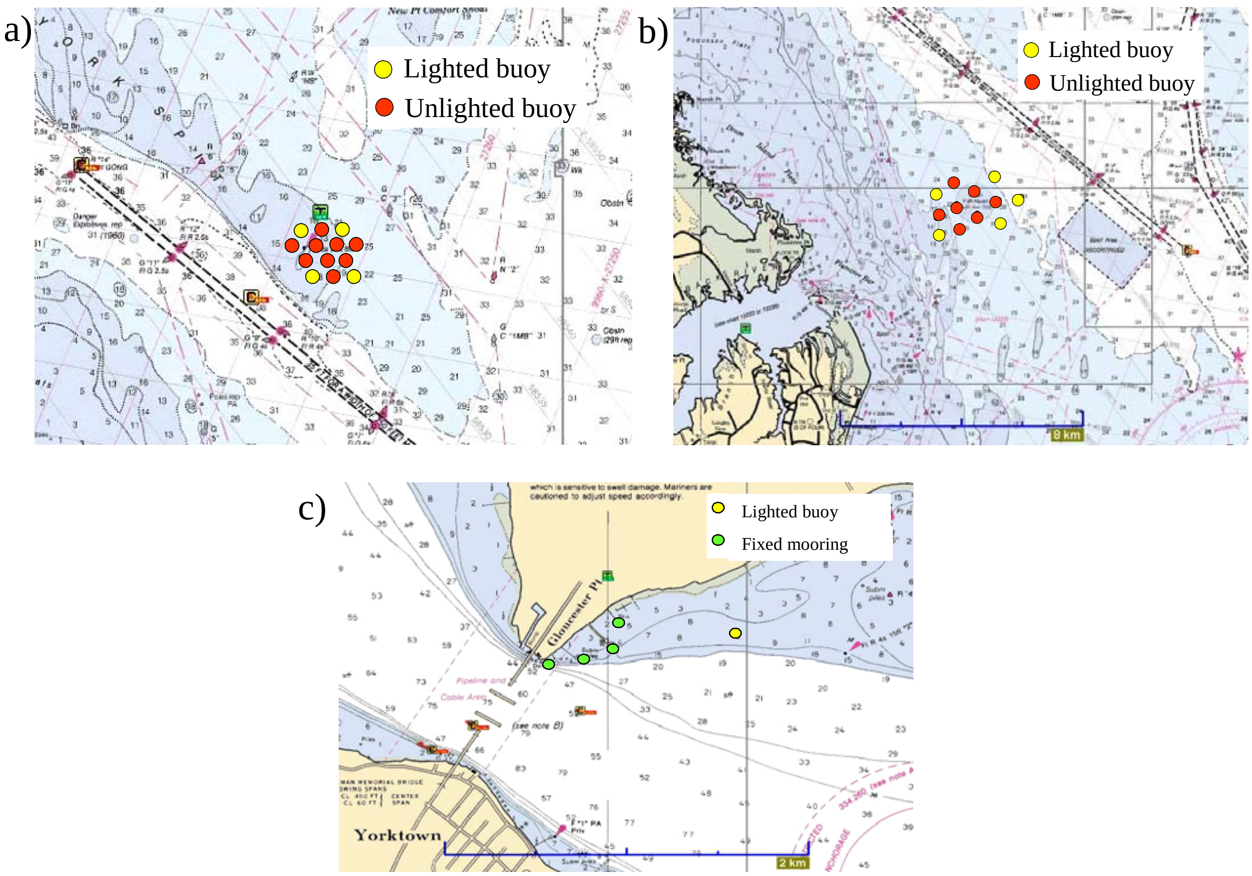


Figure 3. Number of individual summer flounder at Back River reef (blue), York Spit light (grey), and Gloucester Point piers (black) detected between June 2006 and March 2007.

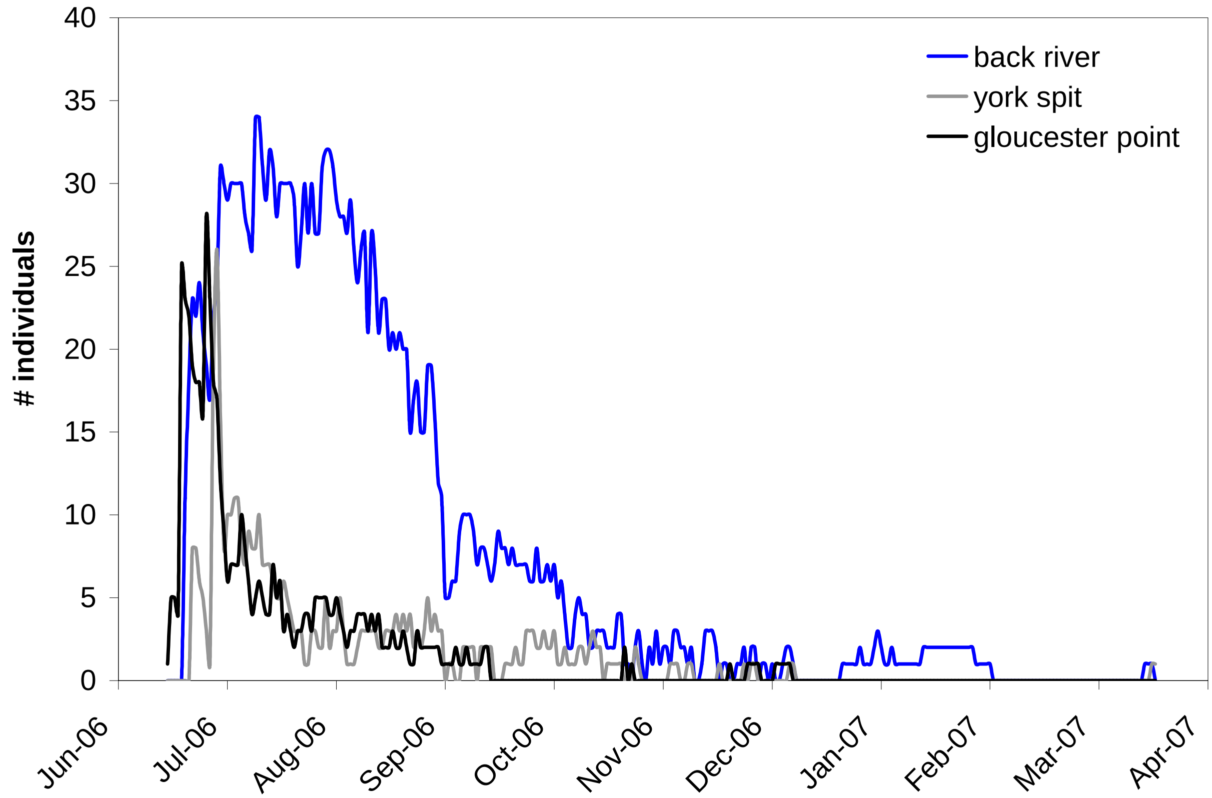


Figure 4. Dates of detection for individual summer flounder tagged and released at Back River reef (N=39), Gloucester Point piers (N=40), and York Spit light (N=39). Two individuals that died soon after release were not included in this figure. The site at which each fish was detected is indicated by color: Back River reef = black, Gloucester Point piers = blue, York Spit light = grey. Detections after 23 March 2007 (vertical line) were from 3 receivers recovered by divers on 06 June 2007 at Back River reef.

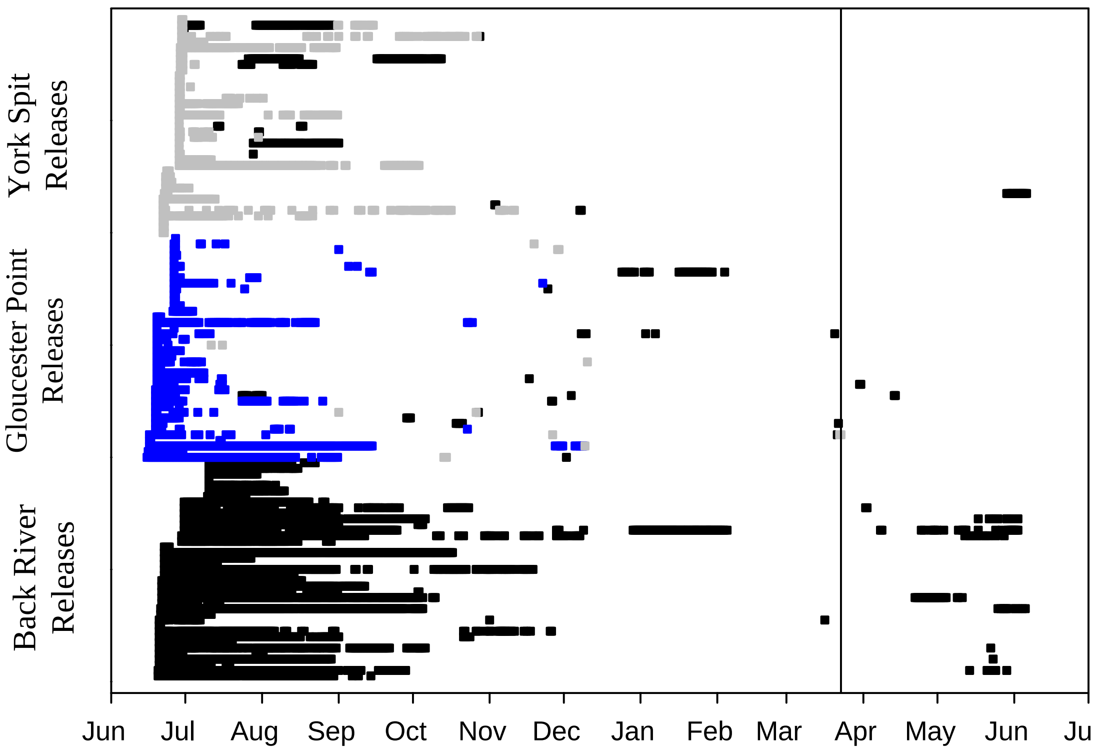


Figure 5. Dispersal curve for summer flounder at Back River Reef based on the Kaplan-Meier estimator with staggered entry (Pollock 1989b). Week 1 begins on 20 June 2006; the last remaining fish dispersed from Back River Reef in week 34 (4-10 February 2007). This curve is based on a total of 39 fish tagged and released alive at Back River reef and 4 fish originally tagged at York Spit light (see text for explanation).

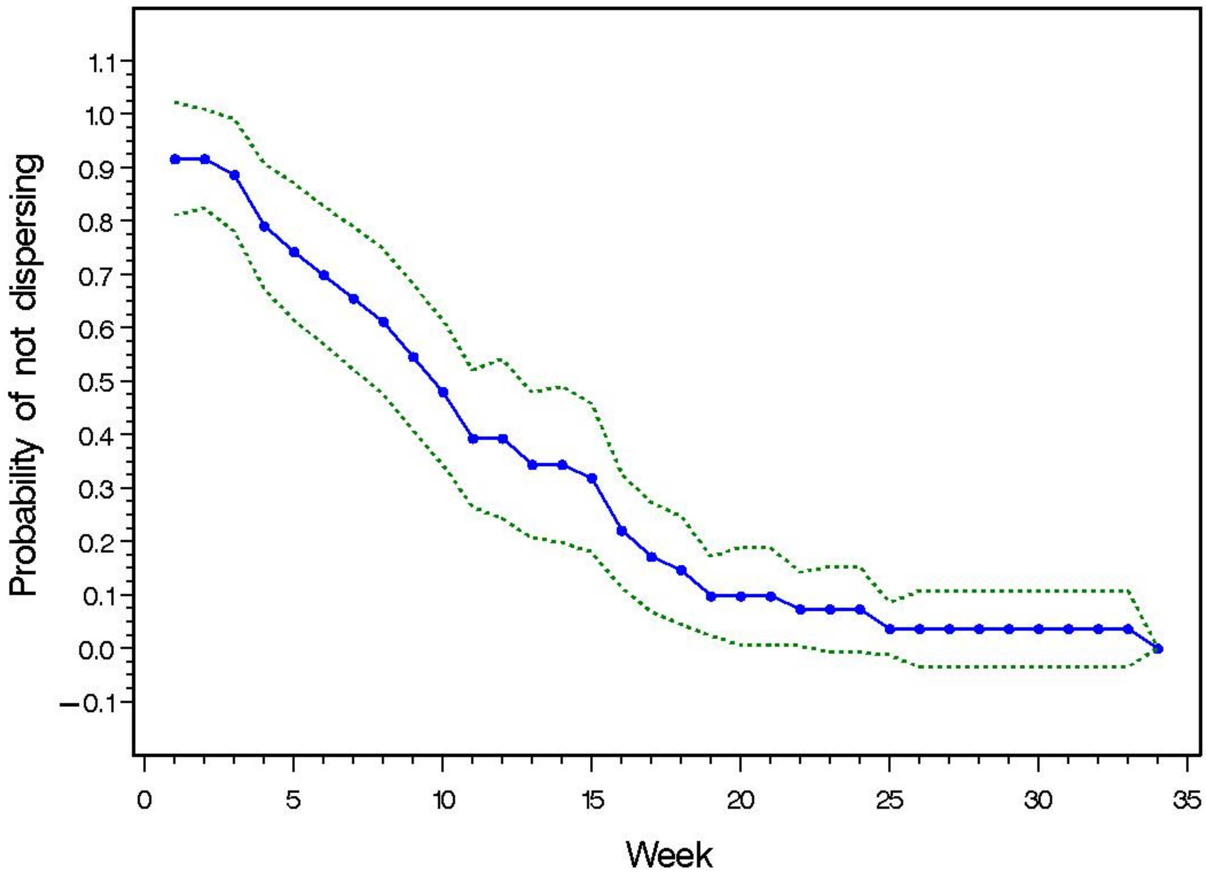


Figure 6. Dispersal curves for small (<430 mm TL) and large (>430 mm TL) summer flounder at Back River reef based on the Kaplan-Meier estimator with staggered entry (Pollock et al. 1989b). Week 1 begins on 20 June 2006; the last remaining fish dispersed from Back River reef in week 34 (4-10 February 2007). These curves are based on a total of 39 fish tagged and released alive at Back River reef and 4 fish released at York Spit light (see text for explanation). The blue dotted line is the dispersal curve for small fish; the green solid line is the dispersal curve for large fish. For clarity, the 95% confidence intervals were omitted, but these intervals overlapped throughout the period of study. Size had no significant effect on dispersal of summer flounder (log-rank test, *W*=0.488, P=0.516)

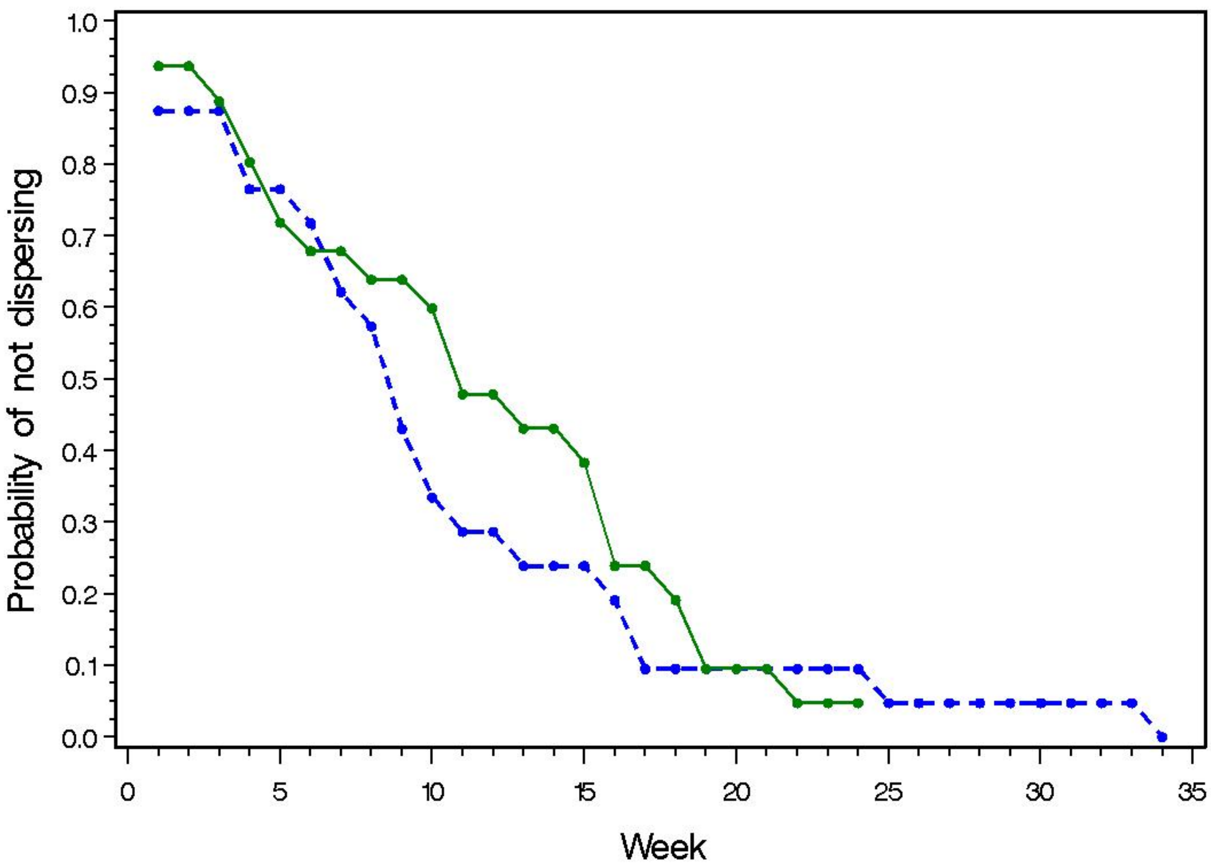
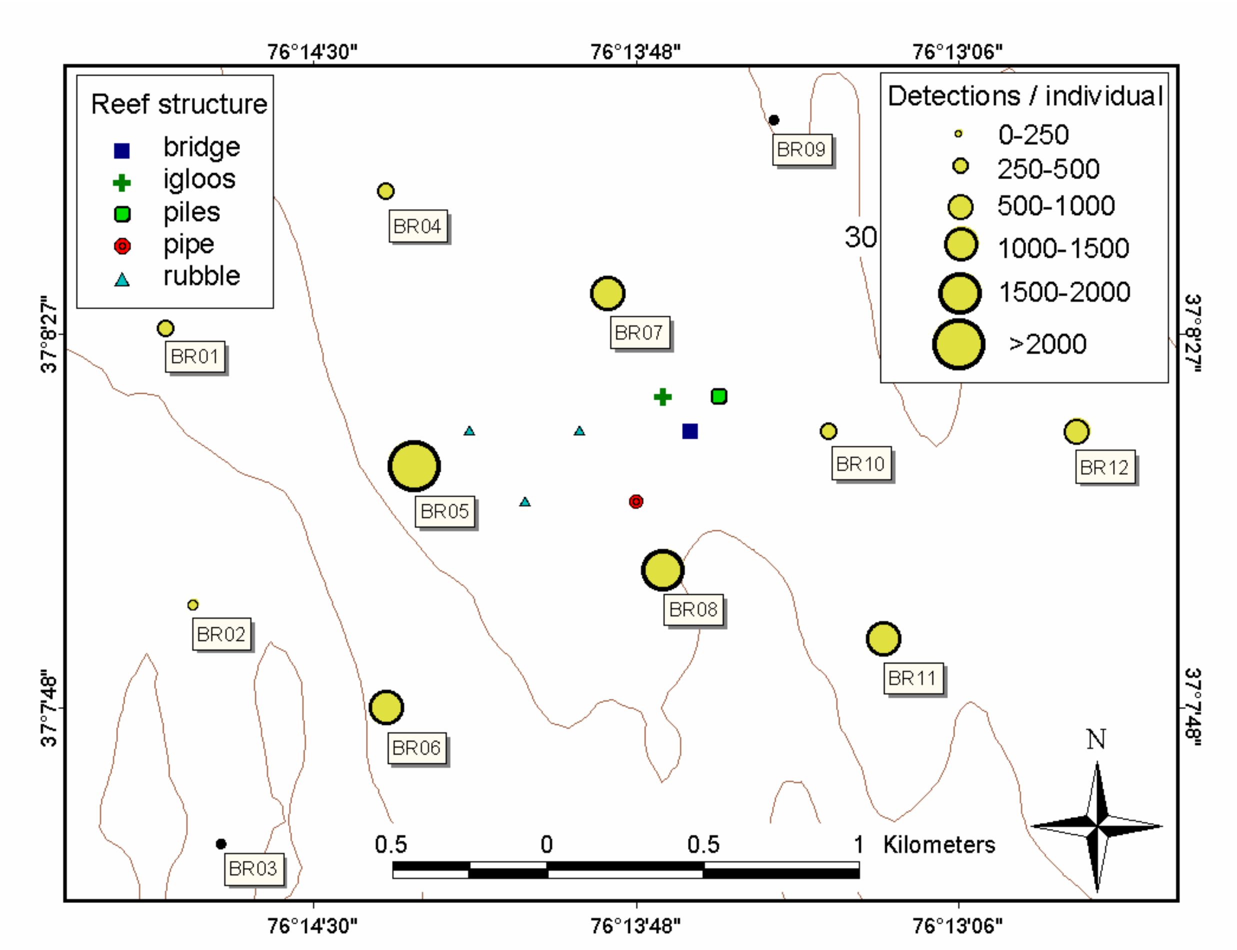
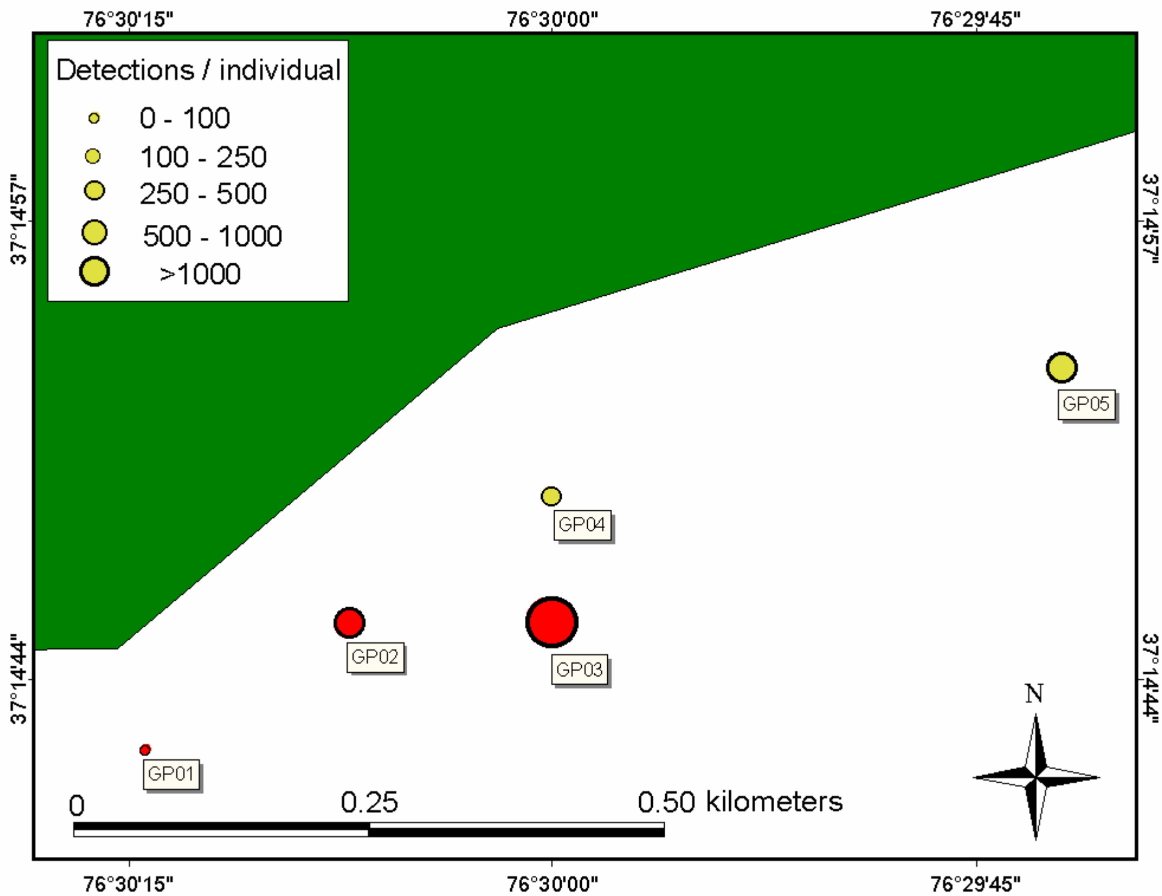


Figure 7. Detections per individual for each receiver at a) Back River reef, b) Gloucester Point piers, and c) York Spit light. The structure at Back River reef was placed within the fish haven by Virginia's artificial reef program. Receivers that were not recovered (BR03, BR09, and YS01) are indicated by black symbols (filled circles). Receivers that experienced a malfunction during the course of the study (GP01, GP02, GP03, YS05) are indicated by red symbols in (b) and (c). Circle diameters for un-recovered and malfunctioning receivers are proportional to the number of detections per individual at that receiver. Note that the detections/individual and distance scales are different for each site.

a)



b)


76°30'15"
76°30'00"
76°29'45"
37°14'57"
37°14'44"
Detections / individual
0 - 100
100 - 250
250 - 500
500 - 1000
>1000
GP01
GP02
GP03
GP04
GP05
N
0
0.25
0.50 kilometers

c)

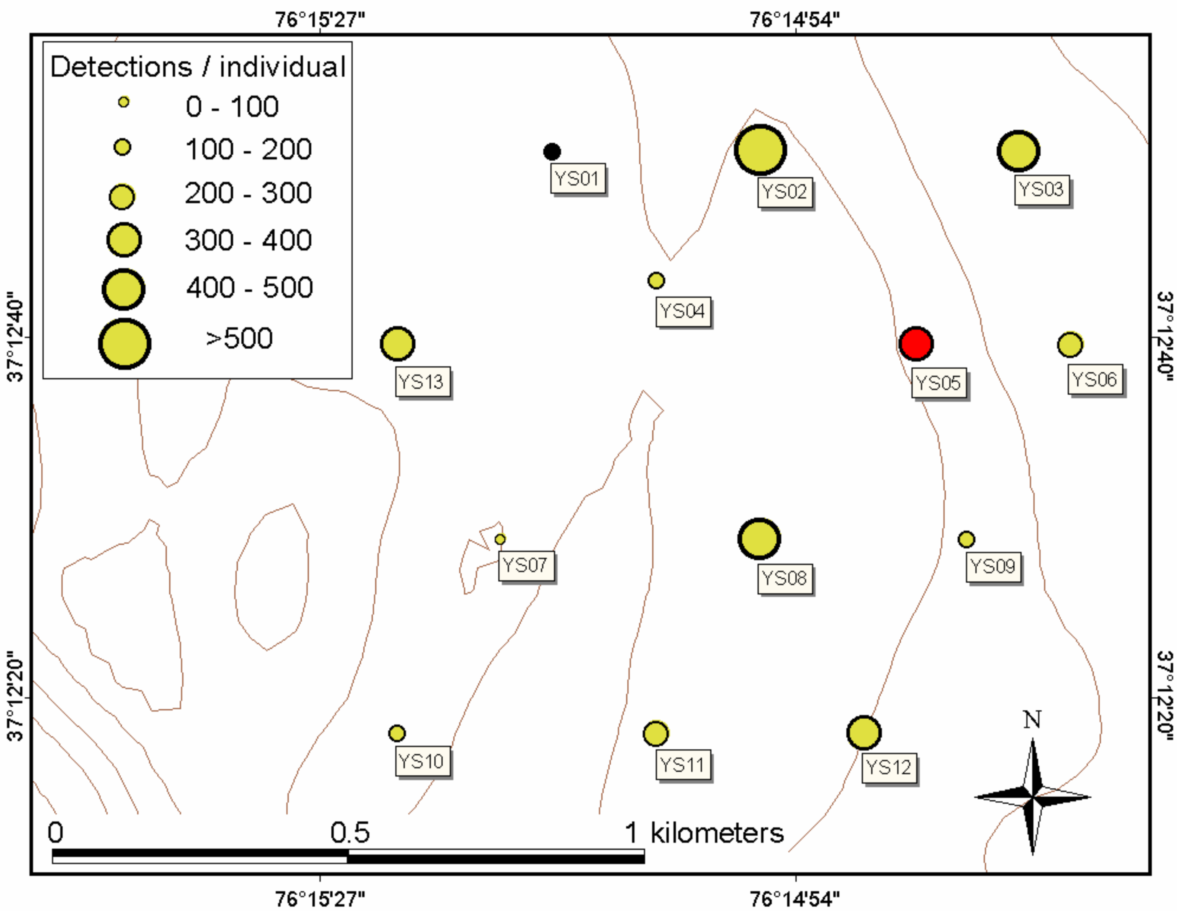
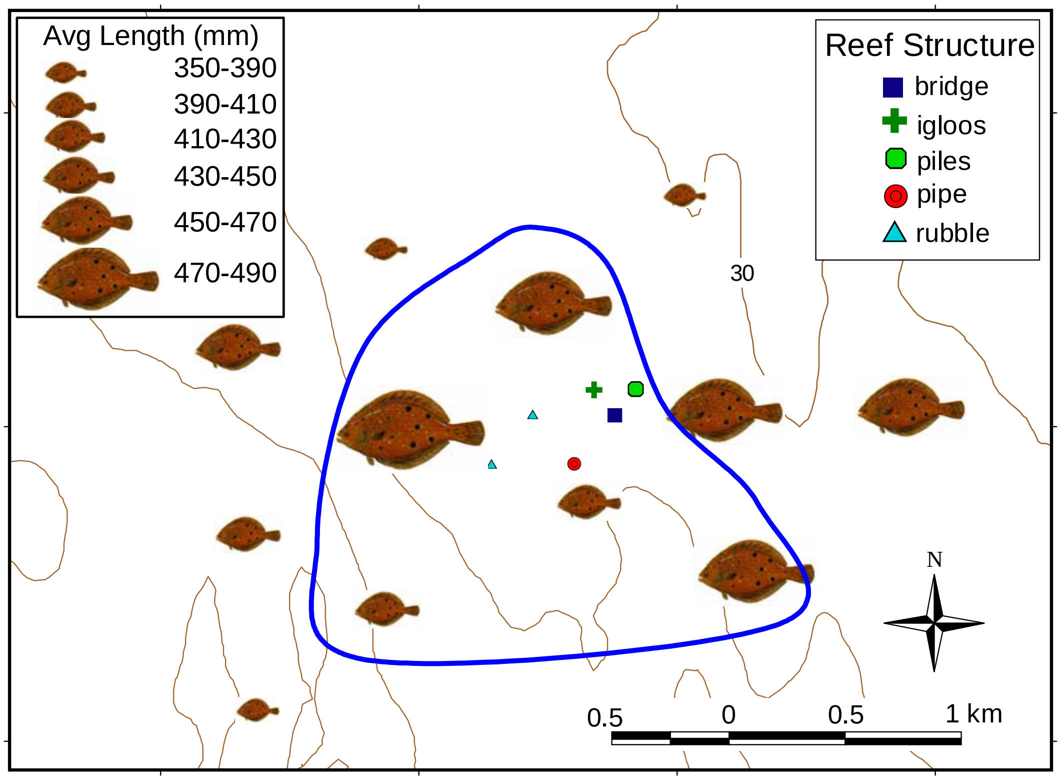

76°15'27"
76°14'54"
Detections / individual
0 - 100
100 - 200
200 - 300
300 - 400
400 - 500
>500
YS01
YS02
YS03
YS04
YS05
YS06
YS07
YS08
YS09
YS10
YS11
YS12
YS13
37°12'40"
37°12'20"
N
0
0.5
1 kilometers
76°15'27"
76°14'54"

Figure 8. Mean total length (mm) of fish detected at each receiver at Back River reef. Mean lengths were weighted based on the number of detections of each fish at each receiver. The blue line surrounds the five receivers with the most detections (see figure 7a).



Appendix I. Poster used to alert anglers to the summer flounder acoustic tagging project and the importance of releasing tagged fish alive.